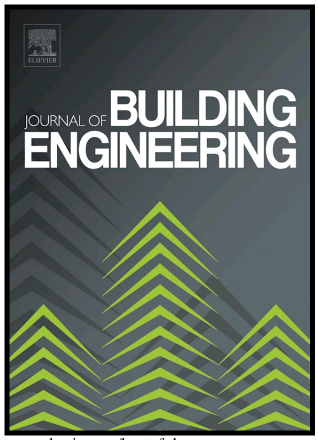


www.elsevier.com/locate/jobe

Energy Consumption in Buildings: A Correlation for the Influence of Window to Wall Ratio and Window Orientation in Tripoli, Libya

Samah K. Alghoul, Hassan G. Rijabo, Mohamed E. Mashena

PII: S2352-7102(17)30189-4
DOI: http://dx.doi.org/10.1016/j.jobe.2017.04.003
Reference: JOBE242

To appear in: *Journal of Building Engineering*

Received date: 28 June 2016
Revised date: 3 April 2017
Accepted date: 4 April 2017

Cite this article as: Samah K. Alghoul, Hassan G. Rijabo and Mohamed E Mashena, Energy Consumption in Buildings: A Correlation for the Influence o Window to Wall Ratio and Window Orientation in Tripoli, Libya, *Journal o Building Engineering,* http://dx.doi.org/10.1016/j.jobe.2017.04.003

Energy Consumption in Buildings: A Correlation for the Influence of Window to Wall Ratio and Window Orientation in Tripoli, Libya

Samah K. Alghoul*, Hassan G. Rijabo, Mohamed E. Mashena
Department of Mechanical and Industrial Engineering, University of Tripoli, Tripoli-Libya.
*s.alghoul@uot.edu.ly

Abstract
This study has been conducted to investigate the influence of window to wall ratio (WWR) and window orientation (WO) on cooling, heating and total energy consumption. The study aims to provide architects with a simple correlation for proper design of facades for office buildings from an energy consumption point of view. The work includes a case study, in which an external wall of a small office space located in the city of Tripoli, Libya was analyzed. Walls with WWR between 0 and 0.9, and with orientation varied in steps of 45 degrees (i.e., facing all eight cardinal and intercardinal directions) were considered. EnergyPlus software was used for energy simulation with "OpenStudio plugin for SketchUp" as an interface. Results indicate that increasing WWR produces an increase in cooling energy consumption and a decrease in heating energy consumption. Cooling energy consumption is found to be substantially higher than heating energy consumption, however, when adding windows to southern walls, cooling consumption drastically increases, while heating energy consumption decreases to zero due to passive solar heating. In general, the effect of adding windows to facade results in an increase in annual total energy consumption by 6% to 181% for the cases explored in this study. Finally, a correlation representing the relation between total energy consumption, WWR and WO has been established in this paper.

Keywords: window to wall ratio, window orientation, energy consumption, energy simulation, EnergyPlus, energy correlation

1. Introduction
The study of building energy performance has been an important issue in past decades. The main goals of those studies is to reduce energy consumption, reduce carbon emission and to develop sustainable energy resources. Energy consumption in buildings is proved to have an important share of the world energy demand and therefore it requires intensive research. Pérez-Lombard et al. [1] stated that energy consumption by both residential and commercial buildings in developed countries account for 20% to 40% of total energy used and Alghoul et al. [2] reported that buildings are responsible for more than 40% of energy consumption in some developing countries. For commercial buildings energy is mainly consumed in lighting, while for residential buildings the consumption is mainly for heating and cooling [3]. Energy performance of buildings highly depends on building envelop including size of windows; as windows are responsible for about 20 to 40% energy loss as described by Lee et al. [3] who has reported this as a finding of BülowHübe [4]. Glazed building facade imposes itself as an icon for developing cities. The inclusion of large area of glazing in facades requires in depth studies to avoid high energy consumption for cooling and heating during the year.

Construction of new commercial buildings in Libya has increased significantly in recent years with an increased trend in the implementation of fully glazed façades. Commercial buildings consumed 14% of total energy produced in Libya [5]. The majority of energy use in commercial buildings is related to lighting and space heating and cooling, which is approximately 53% of their total energy consumption.

Fenestration play important roles in terms of energy performance. Due to solar gains through windows, a relative reduction in heating loads during winter is accomplished, however this will be overcome by the increase in building loads during summer. On the other hand, windows are also considered as a primary source of heat loss in winter, as their insulating value can be very low compared to buildings external walls and roofs [6]. Fenestration are particularly exposed to high heat gain and loss in buildings since they usually have less thickness, highly conductive materials and exposed to direct heat gain from solar radiation [7]. In the context of commercial buildings, many authors pointed out that air conditioning systems are responsible for major participation in annual electricity consumption [8]. In a study carried out for hot arid areas the fully glazed façade was responsible for 45% of the building cooling load [9]. Therefore, window size and orientation are important parameters that might affect building performance to a certain extent.

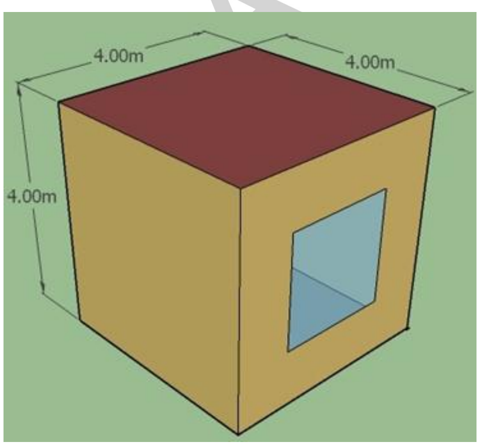
A previous finding was that buildings' windows should be minimalized in size in order to limit the heat gain or heat loss of buildings [10]. However, windows have other important functions such as allowing entrance of natural light into buildings. Additionally, researchers have approved that there are benefits of natural lightings and exterior view [10–13]. Therefore, windows design need proper planning in order to satisfy its purpose of providing natural lighting and external view while maintaining a balanced energy performance of buildings.

In this study, the effect of window to wall ratio and window orientation on annual heating and cooling energy consumption in an office room in the city of Tripoli is investigated for simple double-glazed (air filled) window. The EnergyPlus software is used to calculate heating, cooling and total energy consumption for WWR values between 0 and 0.9, and for all eight cardinal and intercardinal orientations.

2. Site and Material Information

An office space has been chosen for the simulation in Tripoli climatic region (32.7° N latitude; 13.08° E longitude). The office dimensions are (4.0×4.0×4.0 m, l×w ×h) as shown in Fig.1. Weather data used in this simulation is International Weather Files For Energy Calculations 2.0 (IWEC2) for the city of Tripoli, Libya [14].

Office's external wall is designed based on [15]. Schematic of the wall constructions is shown in Fig. 2, and specifications are shown in Table 1. This type of wall construction is typically used in office buildings in Libya.



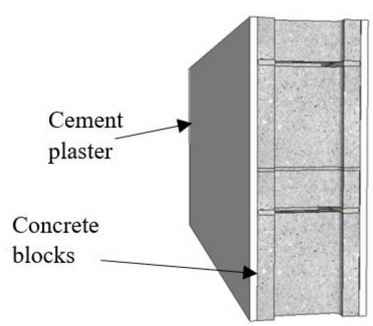


Fig. 1. Schematic of office room under study

Fig. 2. Schematic of typical wall construction

Table 1 Wall constructions and specifications

Property	Units	E1- 20 mm cement plaster	C7-200 mm low density concrete block	E1-20 mm cement plaster
Roughness	-	smooth	Medium rough	smooth
Thickness	m	0.02	0.2	0.02
Conductivity	W/m.K	0.727	0.571	0.727
Density	kg/m3	1602	609	1602
Specific Heat	J/kg.K	840	840	840
Thermal Absorptance	-	0.9	0.9	0.9
Solar Absorptance	-	0.4	0.5	0.4
Visible Absorptance	-	0.4	0.5	0.4

A double clear glazed, air filled, window is chosen in this study. The thickness of glazing layer is 3 mm while the thickness of the air layer is 13mm. Optical properties of glazing used in this work are shown in Table 2.

Table 2 Optical Properties of glazing materials

Optical properties	Clear 3 mm
Solar Transmittance at Normal Incidence	0.837
Front Side Solar Reflectance at Normal Incidence	0.075
Back Side Solar Reflectance at Normal Incidence	0
Visible Transmittance at Normal Incidence	0.898
Front Side Visible Reflectance at Normal Incidence	0.081
Back Side Solar Reflectance at Normal Incidence	0
Infrared Transmittance at Normal Incidence	0
Front Side Infrared Hemispherical Emissivity	0.84
Back Side Infrared Hemispherical Emissivity	0.84

Overall heat transfer coefficient of the window is equal to 2.72 W/m^2. K and other window attributes that considered in this study are shown in Table 3.

Table 3 Windows attributes

Property	Double clear 3 mm /13 mm Air field
Over all U-factor	2.72 $W/m^2.K$
Solar Heat Gain Coefficient	0.764
Visible Light Transmittance	0.812
OpenStudio Type	OS: Construction
Number of Panes	Double pane
Tint	Clear

3. Methodology

The office space model chosen in this has one window placed on external wall. All opaque building components of the reference office are considered as adiabatic, with the exception of a wall that includes a window. Windows with different WWR were considered, and the office was rotated in steps of 45 degrees each time to make the wall face all eight cardinal and intercardinal directions.

EnergyPlus simulation engine with SketchUp and OpenStudio software were used to calculate required cooling and heating capacity and energy consumption for the office room described above. SketchUp was used to draw and create model geometry, while OpenStudio is used to modify model properties: construction, materials, occupancy, internal loads and schedules [16]. Then, EnergyPlus is used to perform an annual energy simulation [17,18]. Finally, obtained results are presented in OpenStudio. The workflow of software used in this study is explained in Fig. 3.

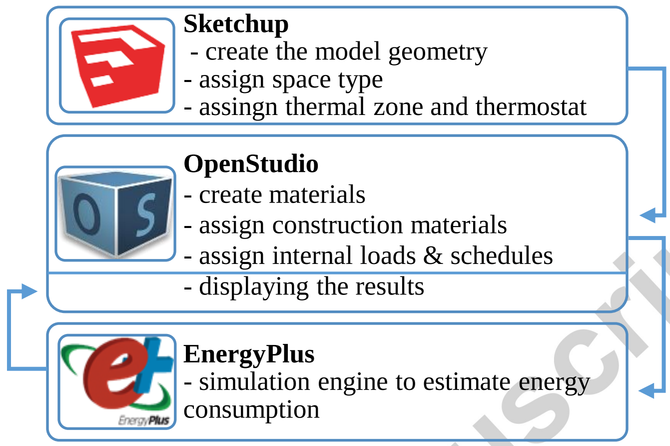


Fig. 3. Workflow for modeling and simulating the problem

EnergyPlus performs a zone heat balance for load calculations. Zone heat balance calculations are divided into surface and air components. TRAP and DOE-2 algorithms [17] were selected for inside and outside surface convection, respectively, and Conduction Transfer Function (CTF) solution algorithm was selected for calculations of conduction through the wall. EnergyPlus calculates heating and cooling loads required to maintain a zone at preset set-points conditions which described in next section.

4. Energy Simulation Setup

In this paper, internal gains due to people, lighting and electric appliances are estimated according to ASHRAE [15]. Due to the exaggeration of the load when using EnergyPlus Ideal Air loads for the estimation of cooling and heating loads[19], a unitary HVAC system is used in order to study the performance of the office room.

Adopted design parameters and operating conditions are listed below:

- Weather file: LBY_Tripoli.620100_IWEC2
- Occupancy density: one person
- Heating set-point: 21°C (07:00 – 19:00) & 15.6°C (rest of the day)
- Cooling set-point: 24°C (07:00 – 19:00) & 26.7°C (rest of the day)
- Installed power of the artificial lighting system: 10.7 W/m^2
- Plug and process: 6.9 W/m^2
- Air changes per hour: 1/hr.
- Infiltration flow rate (Flow / Exterior area): 0.3 $L/s\text{-}m^2$
- Ventilation flow rate: 9.44 L/s-person
- Cooling sensible heat ratio: 0.7

5. Results and Discussion

The results presented below show the influence of window to wall ratio and window orientation on annual energy consumption for a clear double-glazed window of an office space located in Tripoli city, Libya.

a) Energy consumption due to total load

In this section, the effect of changing window to wall ratio and orientation of double glazed window on energy consumption is discussed. Loads affecting the energy consumption in this case are heat transmitted through window & wall, people load, infiltration, ventilation, lighting and equipment.

Fig. 4 shows the effect of WWR on annual heating energy consumption. The values of energy consumption are presented as a ratio of annual values per meter square of wall area. As seen in the figure, addition of double glazed window decreases annual heating energy requirement substantially as compared with no window case. Wall with southern orientations consumed zero energy consumption for WWR between 0.1 and 0.9, while walls with northern orientations consumed the highest heating energy among all orientations.

The increase in WWR plays an important role to reduce heating energy requirement for north, northeast, and northwest orientations, for example, an increase in WWR from 0.1 to 0.9 for north orientation will reduce annual heating energy consumption from 2.3 kWh/m^2 to 0.3 kWh/m^2.

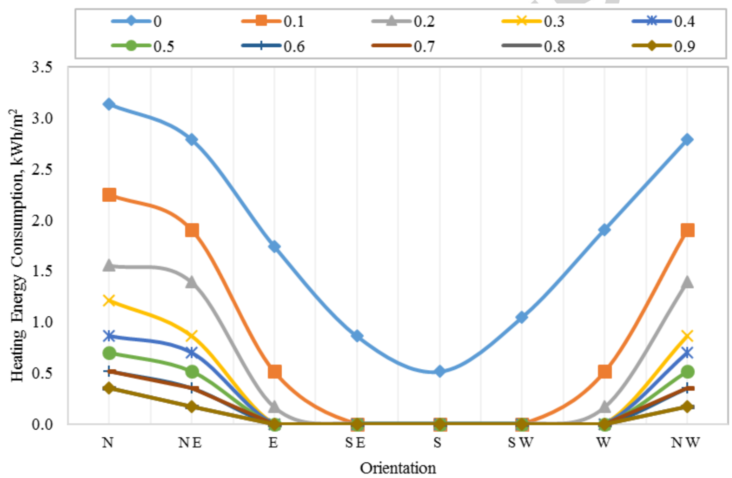


Fig. 4. Annual heating consumption for different WWR and orientations

The annual cooling energy consumption is shown in Fig. 5. As shown increasing WWR causes an increase in cooling energy required for all orientations. The increase in cooling load and therefore cooling consumption is imputed to the increase in direct solar load, which runs through the glass window into the room, in addition to long-wave radiation from inside to outside. In general, the results shown in Fig. 5 indicate that increasing the WWR increases cooling energy requirement. Walls with southern orientations consumed the highest cooling energy for all WWR, while walls with northern orientation consumed the least cooling energy.

South, southeast, and southwest orientations have the highest cooling energy consumption. A change in WWR from 0.1 to 0.9 for southwest orientation will increase the annual cooling energy from 52 kWh/m^2 to 210 kWh/m^2; i.e., the load has quadrupled for south and southwest walls, tripled for northeast and northwest and increased by nearly 3.6 and 3.8 times for east and west orientations walls, respectively.

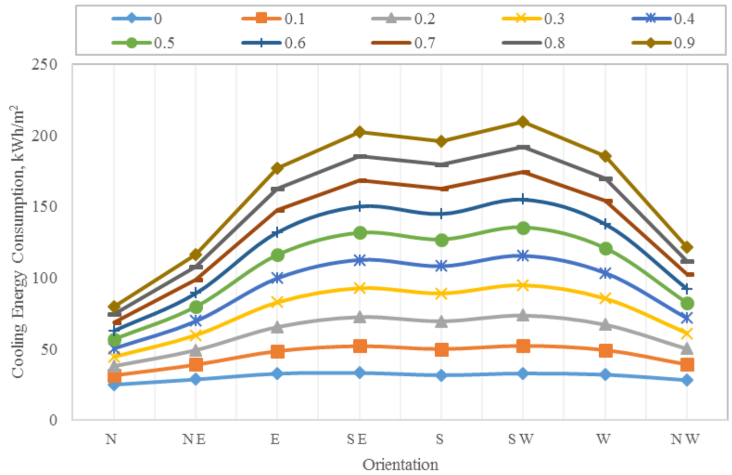


Fig. 5. Annual cooling consumption for different orientation and WWR

The total annual energy consumption per unit area is estimated for all loads for the office, and is shown in Fig. 6. As seen in the figure, the highest total energy consumption occurs at south, southeast and southwest orientations and the values increase as WWR increases.

In general, for Tripoli region, the heating season starts approximately in November and lasts until March, while the cooling season begins on May and ends in September. The heating season required less energy consumption compared to cooling season, which is due to two reasons; (1) the ambient temperature for winter season is not extremely low, while in summer season the climate is very hot and humid. (2) the winter climate for Tripoli region has more sunny days and that is good to use the solar energy penetrated through the window for heating and therefore reducing heating energy consumption.

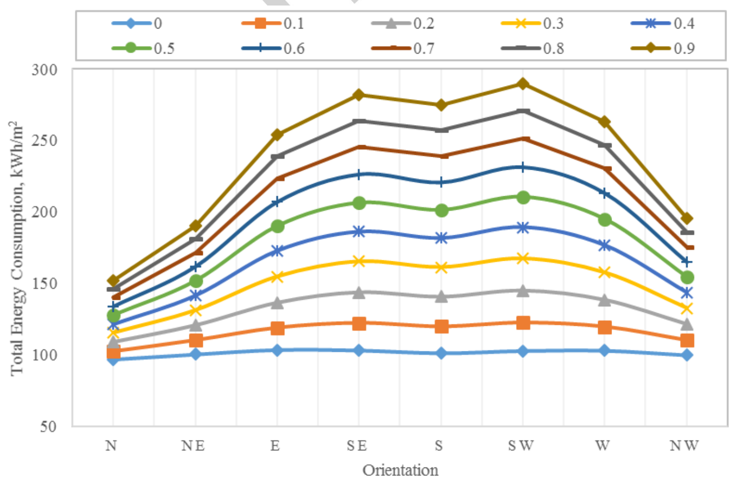


Fig. 6. Annual total energy consumption for different orientation and WWR

In order to simplify the results for architects for decision making in the improvement of designing façade of office buildings from an energy point of view, bar charts, Fig. 7 and Fig. 8, were presented here. They show the increase in energy consumption due to adding windows with different WWR and WO. In other words, the comparison in this case is relative to the office room without windows and that value is defined in this paper as energy consumption ratio (ECR).

$$\mathrm{ECR} = \frac{\mathrm{E(WWR,WO)}}{\mathrm{E(0,WO)}} \qquad (1)$$

Where WO is the orientation of the window/wall under study, E (WWR, WO) is the energy consumption at certain WWR and WO and E (0, WO) is the energy consumption for the wall without window.
The increase in total energy consumption due to adding the window reaches a maximum percentage of 181% for southwest wall with WWR equal to 0.9 while the minimum increase in energy consumption is 6% for north wall with WWR equal to 0.1.

From the above data, a correlation was developed in this work to represent a relation between total energy consumption as a function of WWR and the orientation WO as follows:

$$\mathrm{ECR} = 0.63\ \mathrm{WWR}^{1.02}\ e^{0.0134\mathrm{WO} - 3.64\times10^{-5}\mathrm{WO}^2} \qquad (2)$$

Where WO is measured in degrees clockwise from north. This correlation fits very well with the simulated data and therefore can be used for the calculations of total energy consumption ratio. It has a correlation coefficient of 0.99 and an average error of 4.7%.

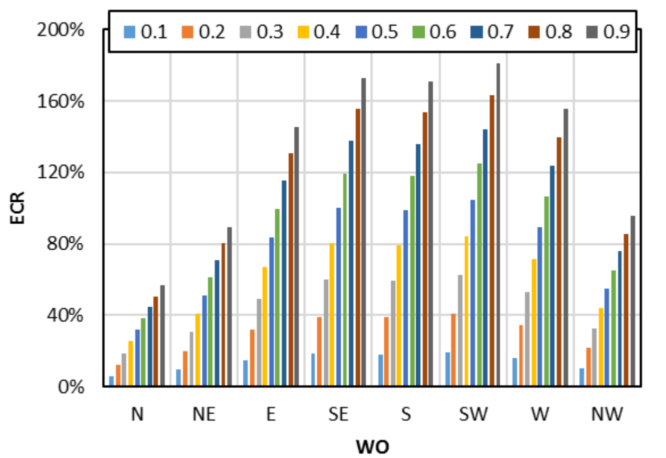


Fig. 7. The increase in total energy consumption as a function of WO

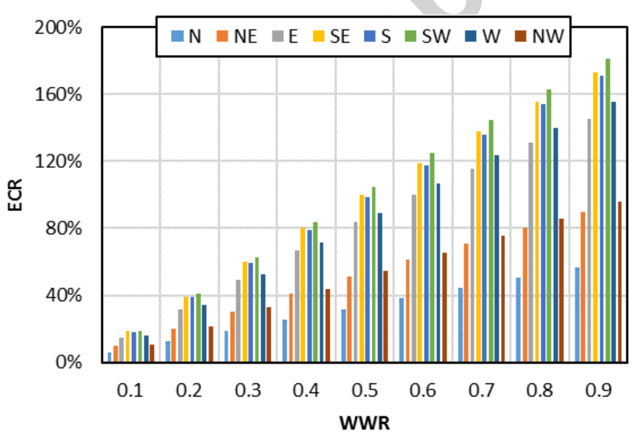


Fig. 8. The increase in total energy consumption as a function of WWR

b) Contribution of window to load

Fig. 9 and Fig. 10 summarize the heating and cooling consumption due to window only (excluding other energy sources). Similar to the previous results, the energy consumption is given as a ratio of annual values per meter square of wall area.

As seen in Fig. 9, the annual heating is reduced (negative sign) by increasing WWR when compared to that amount needed for wall without window. This is due to utilization of solar energy that enters the space through the window. It contributes to the reduction of the annual heating load for the office room. Increasing WWR for south, southeast, and southwest orientations does not influence heating energy for those orientations. Similar behavior is observed for east, and west orientations but with WWR greater than 0.3. For north, northeast, and northwest, increasing WWR always results in reduction of heating energy. The increase in WWR to 0.9 reduced the annual heating energy by 2.8 kWh/m^2.

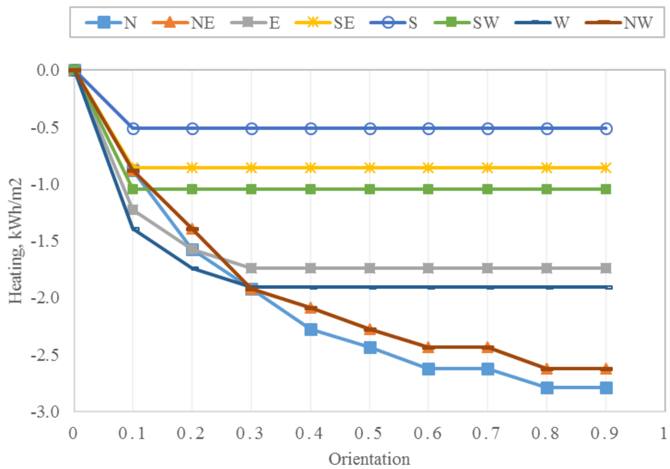


Fig. 9. Annual heating energy reduction due to window

Annual cooling energy required by adding window to the office room is shown in Fig. 10. As seen in the figure, the increase in WWR for different orientations causes an increase in annual cooling energy for the space. As concluded before, southwest, southeast, and south orientations have the highest cooling energy. This reaches a maximum for southwest orientation of 177 kWh/m^2 for WWR equal to 0.9. East and west orientations show similar behavior but with lower consumptions. In general, cooling energy for both northwest and northeast is higher than that for north.

Solar heat gain is the dominant cause for cooling load of a space. Thus, when a window is added to a wall of a space that has no windows, the cooling load, and consequently cooling energy requirement, may increase by as much as 4 times depending on window to wall ratio WWR and orientation.

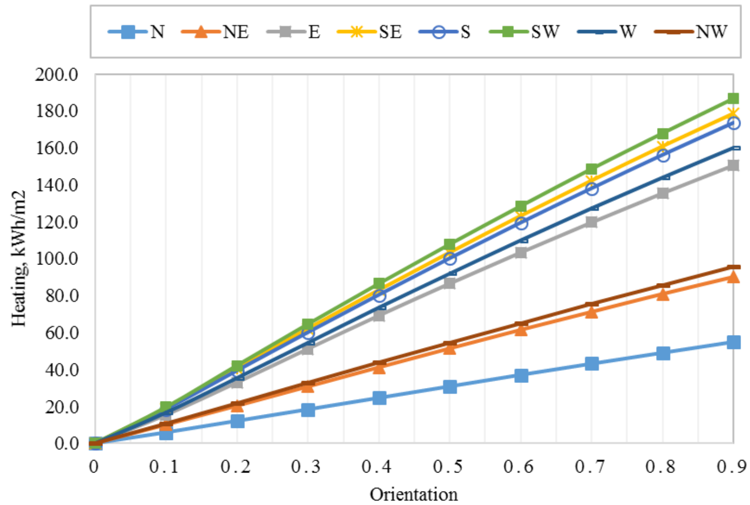


Fig. 10. Annual cooling energy added due to window

6. Conclusions

In this study, the effect of window to wall ratio and window orientations on cooling and heating annual energy consumption was investigated for a clear double-glazed window. The results presented for an office room in the city of Tripoli, Libya and obtained by using EnergyPlus software with OpenStudio interface. The main conclusion was that increasing WWR results in increasing cooling energy consumption and decreasing heating energy consumption. The study also showed that adding windows to southern walls resulted in high increase in cooling consumption while decreasing heating consumption to zero. Overall, the effect of adding windows to the façade resulted in increasing annual total energy consumption by 6% to 181% for the cases shown in this study depending on WWR and orientation. In addition, the results are summarized in bar charts to help building architects to take into account energy performance issue while trying to make attractive building designs. A correlation between total energy consumption, window to wall ratio, and window orientation is established in this work. In order to get more generalized form, this correlation needs more development for different wall and window types and for different sites in the world.

References

[1] Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy and Buildings 2008;40:394–8. doi:10.1016/j.enbuild.2007.03.007.

[2] Alghoul SK, Gwesha AO, Naas AM. The Effect of Electricity Price on Saving Energy Transmitted from External Building Walls. Energy Research Journal 2016. doi:10.3844/erjsp.2016.

[3] Lee JW, Jung HJ, Park JY, Lee JB, Yoon Y. Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. Renewable Energy 2013;50:522–31. doi:10.1016/j.renene.2012.07.029.

[4] Bülow-Hübe H. Energy-Efficient Window Systems-Effects on Energy Use and Daylight in Buildings. Journal Article. Lund University, 2001.

[5] GECOL. Annual Report: Statistics 2012. Tripoli: General Electricity Company of Libya; 2012.

[6] Nikoofard S, Ugursal VI, Beausoleil-morrison I. Effect of window modifications on household energy requirement for heating and cooling in Canada. Proceedings of eSim 2012: The Canadian Conference on Building Simulation, 2012, p. 324–37.

[7] Moorjani VB, Asadi S. Assessing the Effects of Glazing Type on Optimum Dimension of Windows in Office Buildings. 50th ASC Annual International Conference Proceedings, Associated Schools of Construction; 2014.

[8] Westphal FS, Andreis C. Influence of Glazed Façades on Energy Consumption for Air Conditioning of Office Buildings in Brazilian Climates. Int Journal of Engineering Research and Application 2016;6:54–60.

[9] Hamza N. Double versus single skin facades in hot and areas. Energy and Buildings 2008;40. doi:10.1016/j.enbuild.2007.02.025.

[10] Chang CY, Chen PK. Human response to window views and indoor plants in the workplace. HortScience 2005;40:1354–9.

[11] Shin WS. The influence of forest view through a window on job satisfaction and job stress. Scandinavian Journal of Forest Research 2007;22:248–53. doi:10.1080/02827580701262733.

[12] Caudill W, Pena W, Kennon P. Architecture and you. Whitney Library of Design, NewYork: 1978.

[13] Cuttle C. People and windows in workplaces. People and Physical Environment Research Conference, Wellington: 1983.

[14] ASHRAE. ASHRAE International Weather Files For Energy Calculations 2.0 (IWEC2). IWEC2 2009. https://www.ashrae.org/resources--publications/bookstore (accessed February 20, 2016).

[15] American Society of Heating Refrigerating and Air-Conditioning Engineers. 2013 ASHRAE Handbook: Fundamentals. Internatio. ASHRAE; 2013.

[16] OpenStudio. OpenStudio User Documentation 2016;2016. http://nrel.github.io/OpenStudio-user-documentation/.

[17] US Department of Energy. EnergyPlus^{TM} Version 8.5 Documentation: Engineering Reference. 2016.

[18] Crawley DB, Lawrie LK, Winkelmann FC, Buhl WF, Huang YJ, Pedersen CO, et al. EnergyPlus: creating a new-generation building energy simulation program. Energy and Buildings 2001;33:319–31. doi:http://dx.doi.org/10.1016/S0378-7788(00)00114-6.

[19] Alghoul S. A Comparative Study of Energy Consumption for Residential HVAC Systems Using EnergyPlus. American Journal of Mechanical and Industrial Engineering 2017;2:98–103. doi:10.11648/j.ajmie.20170202.16.

Highlights

- Windows are responsible for high energy loss from building.
- Cooling energy consumption is substantially higher than heating in Tripoli.
- South facing windows increases total energy consumption drastically.

- Adding windows to facades increase annual energy consumption by 6% to 181%.
- A correlation between energy consumption, WWR and WO is proposed.